ON-LINE QRS COMPLEX DETECTION USING WAVELET FILTERING

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Abstract-**This paper presents a new QRS complex detection algorithm that can be applied in various on-line ECG processing systems. The algorithm is performed in two steps: first a wavelet transform filtering is applied to the signal, then QRS complex localization is performed using a maximum detection and peak classification algorithm. The algorithm has been tested in two phases. First the QRS detection in ECG registrations from the MIT-BIH database has been performed, which led to an average detection ratio of 99.50%. Then, the algorithm has been implemented into a microcontroller-driven portable Holter device. This research is supported by the Hungarian Foundation for Scientific Research, Grant T29830 and FKFP0301/0999 Project.**
***Keywords* - ECG, QRS detection, wavelet transform.**

I. INTRODUCTION

On-line ECG processing systems require a reliable and fast QRS complex detection algorithm. Most on-line algorithms apply a direct method, which sometimes leads to mediocre results. Parameter estimation methods are mostly too complex to be implemented in microcontroller-driven devices. Transformation-based algorithms are usually reported to work off-line, because of the enormous amount of calculations [1]. These are problems to be solved using the new method.

II. METHODOLOGY

The QRS complex detection algorithm consists of two steps. First the wavelet transform is applied to obtain a transformed signal, which contains a few maxima and minima in each period. In the second step these extreme values are detected, and the peaks of the maxima preceded by a long ascent and followed by a long descent of the signal are declared to coincide with the peaks of the R waves.

A. The Wavelet Filtering

Wavelet transform is a linear operator, which decomposes the input signal into components that appear at different resolutions. The first thing needed for a wavelet transform is to choose a convenient mother wavelet. The function $\Psi(t)$ is said to be a wavelet if it has a finite spectrum, that is:

$$\int_{-\infty}^{+\infty} \frac{\left|\hat{\Psi}(w)\right|^2}{|w|} dw = C_\Psi < +\infty , \tag{1}$$

where $\hat{\Psi}(w)$ denotes the Fourier Transform of $\Psi(t)$. This condition implies, that $\Psi(t)$ cannot have a dc component, it is oscillatory and its area is zero:

$$\int_{-\infty}^{+\infty} \Psi(t) dt = 0 . \tag{2}$$

Let us denote by $\Psi_a(t)$ the dilation of $\Psi(t)$ by the positive scale factor a, defined as:

$$\Psi_a(t) = \frac{1}{\sqrt{a}} \Psi\left(\frac{t}{a}\right). \tag{3}$$

The wavelet transform of the function $j(t)$ at scale a and position q is given by the following expression:

$$Wj(a,q) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} j(t) \Psi^*\left(\frac{t-q}{a}\right), \tag{4}$$

where $\Psi^*(a)$ denotes the complex conjugation of $\Psi(a)$. In its digitized form, this formula (5) gets the following aspect:

$$Wj_q = \sum_{k=-d}^{d} c_k j_{q+k} , \tag{5}$$

where d reflects the length of the interval in which the wavelet is defined, and the coefficients contain the wavelet and the energy normalizing factor $1/\sqrt{a}$ [2]. The wavelet we used is defined as:

$$\Psi(t) = \exp\left(-\frac{t^2}{b^2}\right)\cos(2pft) - l , \tag{6}$$

defined in only a p periods of the cosine function, where b is the attenuation factor of the wavelet, f defines its basic frequency, while l is computed such as it eliminates the dc factor.

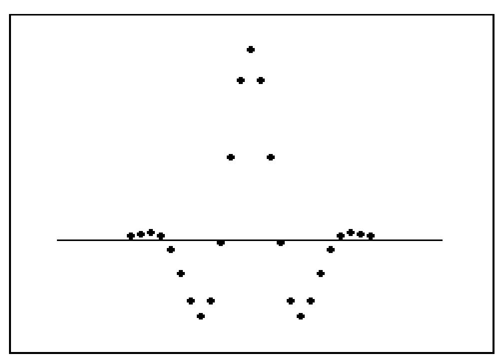

Fig. 1. The aspect of the chosen wavelet

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The output function of this wavelet transform will be our filtered signal. The parameters of this filtering are the attenuation factor b, and the basic frequency f [3].

Our goal is to find those parameter values, which contribute the most to a good QRS detection ratio. The value for parameter p or d will be chosen so that it assures all the significant parts of the sum defined in (5), but it eliminates all additional calculations for the attenuated part of signal, that hardly influence the result.

The effect of this wavelet filtering will be an elimination of low and high frequency components from the signal, in fact it will be similar to a bandpass filtering around the basic frequency f, without causing any phase delay.

B. QRS Complex detection

The QRS complex detection is accomplished using the transformed signal. First we determine the series of consecutive minima and maxima. Then the maxima, which occur after a long ascent and are followed by a long descent, will be declared the peaks of the R waves. The exact threshold value of the criterion long is determined at the beginning from the maximal value of the ascents in the first few seconds. However, considering the fact, that the output signal of the wavelet transform defined according to (5), has values only in the interval [-1,1], a fixed threshold in the range 0.4-0.6 always leads to acceptable results.

C. Adjusting parameters for optimal QRS complex detection

The stability, efficiency and reliability of this method have been studied by varying the value of the main parameters (b, f, d), and checking how the detection ratio depends on them.

III. Results

The algorithm has been tested using ECG registrations from the MIT-BIH database and registrations measured with the Holter system at the Medical Clinic No. 3 of Marosvásárhely (Romania) [4]. Some signal sections can be seen in Fig. 2. The first signal is the measured one, the second is the filtered signal. Localized QRS complexes are represented by vertical lines in the image of the measured signal.

The detection ratio has varied between 98.85% and 100%. The threshold value, if chosen a certain, considerably wide interval, does not influence the detection ratio, which provides stability for the algorithm. In most arrhythmia-free cases there has been no failed detection.

The basic frequency has a strong influence on the detection ratio. Its value has to be around the dominating frequency of the R wave. By choosing a value between 12Hz and 21Hz, we obtain a very good detection ratio; the optimal value, even if it depends from registration to registration or from patient to patient, in every case is very close from 17Hz.

The width of the interval, in which the mother wavelet is defined, should be chosen as 2-2.5 periods of the cosine function in the wavelet's definition. The attenuation factor b should be chosen such a way, that it limits the mother wavelet's values at the boundaries of the interval by 3-5% of its maximum. Fig. 1 represents a wavelet that provides excellent results. Table I gives a summary on the efficiency of the method, measured with ECG registrations from MIT-BIH database.

TABLE I.
DETECTION RATIOS FROM MIT-BIH RECORDINGS

Registration number	Total beats	Failed detections	Detection ratio
104	2230	6	99.73%
105	2572	19	99.26%
108	1763	17	99.03%
201	1963	8	99.59%
203	2982	16	99.46%
222	2484	7	99.72%
228	2053	8	99.61%
Total	16047	81	99.50%

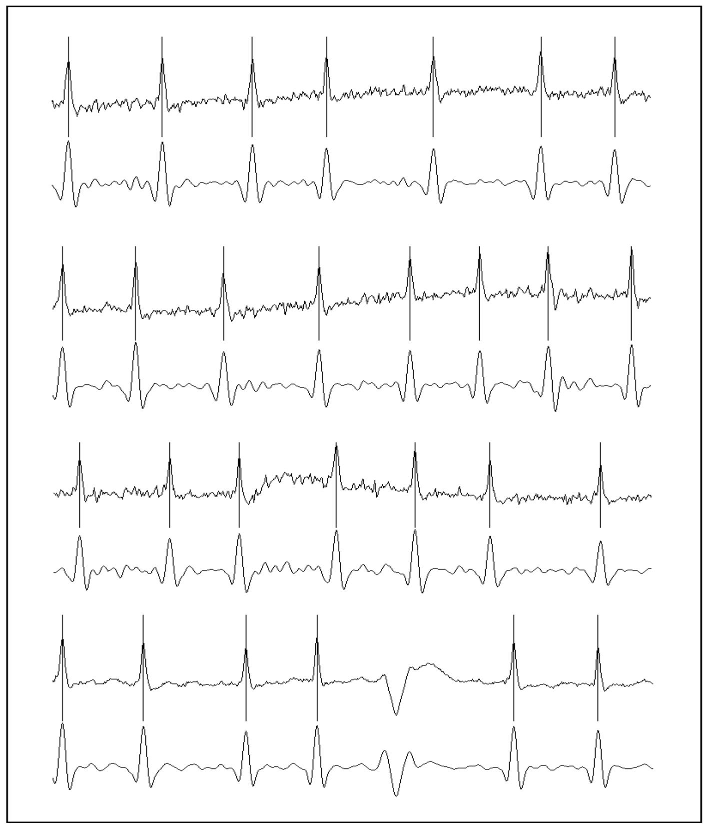

Fig. 2. Measured and filtered ECG signal sections, and localized QRS complexes

IV. Discussion and Conclusion

Having the detection ratio over 99.5%, this method can be called a reliable one, and can be implemented into Holter systems. Wavelet-transform-based methods have been reported many times to require a lot of calculation, which makes it hard to use in on-line signal processing systems. Using modern computers, this method can process a 10-minute registration in a few hundreds of milliseconds. Therefore it can be applied even in case of multi-channel ECG. Experiments show, that the algorithm works in a microcontroller-driven Holter system [4].

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